Hazard Evaluation of Hydrogen-Air Deflagrations Using Latex Balloons

Hiroyasu Saitoh[1], Naoto Uesaka[1], Teruhito Ohtsuka[2], Takaaki Mizutani[2], Yuki Morisaki[1], Hidenori Matsui[2], and Norihiko Yoshikawa[1]

[1]Nagoya University, Nagoya, JAPAN

[2]National Institute of Industrial Safety (NIIS), Tokyo, JAPAN

Corresponding author, H. Saitoh: hsaito@nuae.nagoya-u.ac.jp

Introduction

In connection with the recent development and test use of hydrogen supply station for fuel cell automobile in Japan, the hazards due to deflagrative blast waves were experimentally evaluated using three different size of latex balloons, ranging 5.4 - 1400 litters.

Hydrogen is the lightest gas and diffuses rapidly into the atmosphere to generate flammable mixture. Hydrogen also has wide flammable range of 4 - 75 volume% and small minimum ignition energy of the order of 10^{-2} mJ. This implies that hydrogen-air mixture can ignite just by a weak spark of static electricity. If there is no ignition source in the gas mixture cloud, explosion does not occur. However, once ignition occurs, extensive destruction may occur to the surroundings due to damaging blast waves. The extent of the damage depends on the peak pressure and impulse generated by propagating flames [1, 2]. Accordingly, it is very important to understand combustion phenomena of hydrogen-air mixtures, especially relationship between flame propagation in the mixtures and the blast parameters. Although there are lots of papers dealing with hydrogen leakage and explosions for investigation of accidents [3, 4], we think that accumulation of more reliable experimental data is necessary for better evaluation of the safety and the risk.

In the present paper, we report hydrogen-air deflagration experiment using latex balloons. In order to examine the influence of initial condition of the mixture on flame propagation and the blast parameters, the time evolution of flame velocity and pressure were monitored simultaneously. Moreover, we tried normalization of the blast parameters obtained in several kinds of experimental condition to confirm scaling law [2, 5].

Experimental Apparatus and Procedure

Fig.1 shows a schematic of the experimental apparatus. A latex balloon is fixed on the top of the stainless cylinder. Hydrogen was mixed with air in a mixing chamber in advance and supplied inside the latex balloon. Although hydrogen flames slightly have orange light emission due to impurity of the air or the vibration-rotation spectrum of H_2O [6], small amount of acetylene (less than 0.1 volume%) was mixed with the premixed gas to make flame visible in high-speed video records. As shown in Table 1, we changed equivalence ratio ϕ, diameter of the balloon d, ignition point h, and ignition timing. In the case of ignition after break of the balloon by remote knife edge, the mixture is allowed to diffuse into the atmosphere during flame propagation. This situation is similar to actual gas-cloud-explosion accidents. The collapse of the balloon was detected by the TTL signal from the photo IC that receives the He-Ne laser beam. On the other hand, in the case of center ignition without break of the balloon, we confirmed that the balloon did not break until flame propagated through almost all the volume of the mixture. Therefore, it was relatively easy to evaluate relationship between amount of hydrogen (that is, calorific value) and blast parameters.

ime-series images of the deflagrations were taken by high-speed camera with frame rate of 1,125 or 4,500 fps depending on the condition. Pressure transducers and ion probes were set up around the balloon.

In addition to these experiments, a smaller scale experimental setup of hemispherical latex balloon of 275 mm diameter was used for better understanding of the blast scaling law.

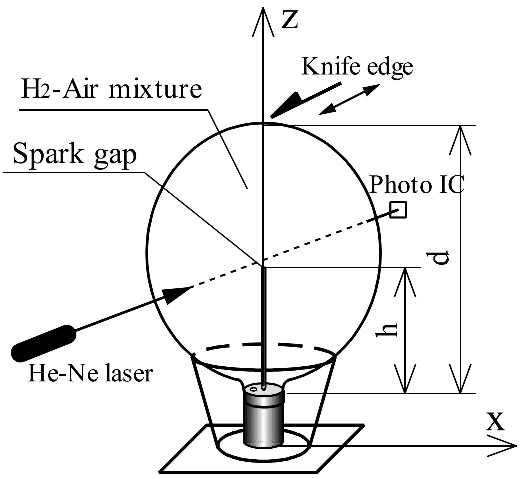

Figure 1 Experimental apparatus.

Table 1 Experimental condition.

ϕ	0.5 ～ 4.0	
d [cm]	65 (150 L)	150 (1400 L)
h [cm]	20	40 75
Ignition way	after break of balloon or without break of balloon	

Results and Discussion

Deflagration Behavior

Figure 2 shows an example of the time-series data of high-speed images, pressure, and ion current signals. Peak over pressure, positive impulse, and flame speed can be obtained by the data. In Fig.2, for example, peak pressure and positive impulse measured by probe CH2 (1.5 m from the center of the mixture) are 6.2 kPa, 46.4 Pa-s, respectively. Upward flame speed in the periphery of the initial mixture can be also estimated by using the ion signal.

The average flame speed between probe CH5 and CH8 (distance: 0.3 m) estimated

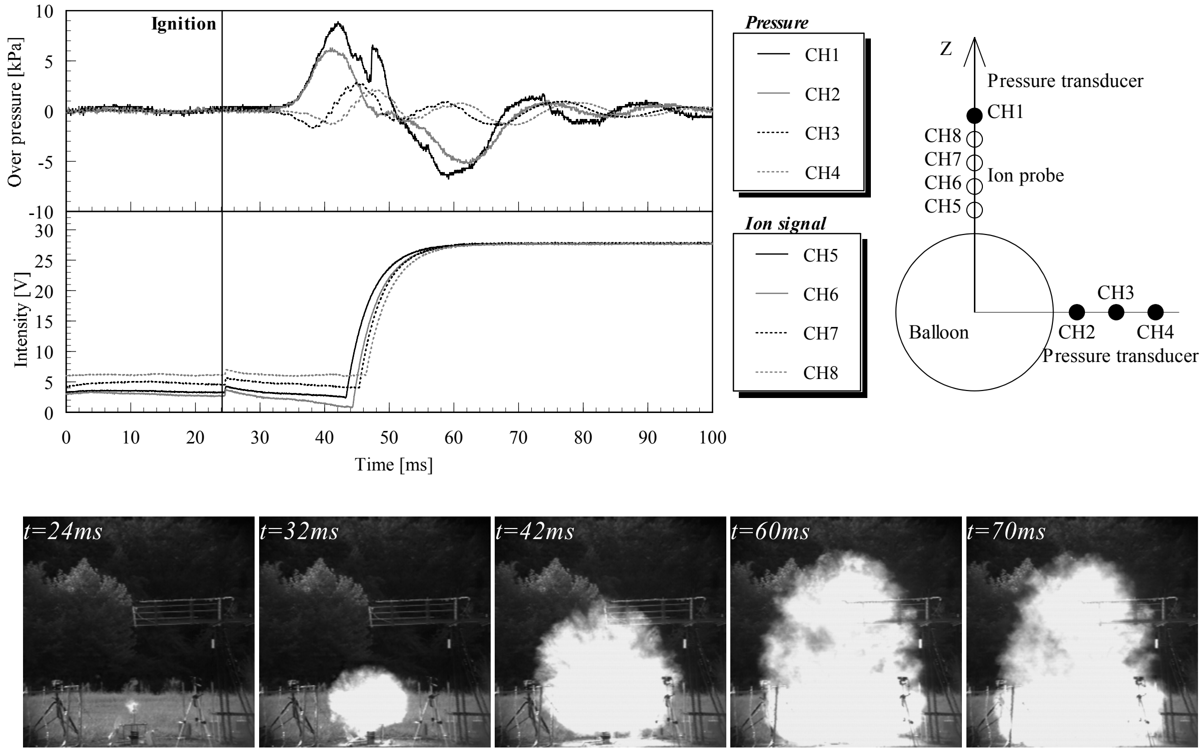

Figure 2 Time-series data of high-speed images, pressure, and ion current signals.
(experimental condition: ϕ=1.8, d=150cm, h=40cm, ignition: after break of balloon)

roughly is about 95.2 m/s in this case, which is much faster than the laminar flame propagation velocity. All the other experimental records were similarly analyzed. As a result, we confirmed that peak over pressure and positive impulse increase as the amount of hydrogen inside the balloon increase. The blast parameters obtained in the case of ignition without break of balloon was greater than in the case of ignition after break of balloon. This fact implies that large amount of hydrogen diffuses into the atmosphere without burning during the flame propagation in hydrogen-air mixtures.

Application of Blast Scaling Law

To all the data obtained in the condition of ignition without break of latex balloon, including spherical and hemispherical deflagration experiments, we applied the Sachs's blast scaling law [2, 5]. Non-dimensional blast parameters are introduced in the scaling law, and peak over pressure and impulse (positive impulse estimated by integration of the first blast wave with positive phase of the pressure signal) obtained for different experimental sizes are normalized as follows:

$$\bar{p} = \frac{p - p_0}{p_0}, \qquad \bar{i} = \frac{i a_0}{E_t^{1/3} p_0^{2/3}}, \qquad \bar{R} = \frac{R}{\left(E_t / p_0\right)^{1/3}}$$

where p is peak over pressure, p_0 atmospheric pressure, i impulse, a_0 sound velocity in

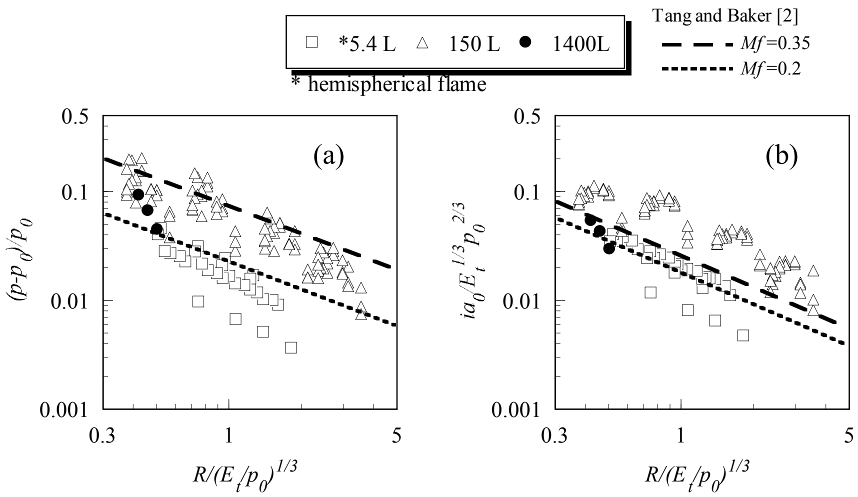

Figure 3 Sachs's scaling law. (a) Normalized peak over pressure versus normalized distance, (b) Normalized positive impulse versus normalized distance.

ambient air, E_t total energy release of gas mixture, R distance from blast source. The relations between the non-dimensional values of peak pressure and impulse versus distance are given in Fig. 3. Although each data of the peak over pressure and positive impulse some scatters, it is confirmed that they decrease depending on the normalized distance with almost same gradient except the case of 1400 L. This tendency is close to the blast curves in Fig. 3 obtained by Tang and Baker [2] for the case of flame speed M_f= 0.2 and 0.35, respectively. As shown in Fig. 3(a), our experimental data of the peak pressure scatter around the blast curves. However, the impulse data for the case of 150 L are above the blast curve in Fig. 3(b). This might be caused by the experimental condition that we conducted the experiment for the case of 150 L in the relatively small explosion-protected room.

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